A modeling approach for locating logistics platforms for fast parcels delivery in urban areas

Olivier Guyon, Nabil Absi, Dominique Feillet, Thierry Garaix

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A MODELING APPROACH FOR LOCATING LOGISTICS PLATFORMS FOR FAST PARCEL DELIVERY IN URBAN AREAS

Olivier Guyon, Ecole des Mines de Saint-Etienne – CMP, France
Nabil Absi, Ecole des Mines de Saint-Etienne - CMP, France
Dominique Feillet, Ecole des Mines de Saint-Etienne - CMP, France
Thierry Garaix, Ecole des Mines de Saint-Etienne - CMP, France

ABSTRACT

This study aims at defining a framework for optimizing, in a sustainable way (i.e. economical, eco-friendly and societal), the location of logistics platforms in urban areas. A first case study for our work is the city of Marseilles (France) which already has a logistics platform right in its centre (ARENC: 41362 m^2 of warehouses and offices).

In this abstract, we first provide a precise description of the problem we intend to solve. We then propose a mathematical model for representing it. Preliminary experimentations, based on the city of Marseilles, are then described; figures and preliminary results which are proposed for this first case study are obtained thanks to a decision-making software we have implemented. Conclusions and future works are finally drawn.

INTRODUCTION

City logistics has raised the interest of many researchers from different communities and countries in the last decade (Taniguchi and Thompson, 2002; Boudouin, 2006; Crainic, 2008; Guyon *et al.*, 2010). The subject of this paper is the location of logistics platforms in the context of fast parcel delivery in urban areas.

Regarding the last miles, fast parcel deliveries is generally managed as follows by carriers. Parcels are supplied to platforms early in the morning (late in the night) and sorted according to their final destination. Trucks are then loaded and drivers start deliveries. Once finished, collection of parcels are started and distributed to platforms in the mid afternoon, so that parcels can be sorted and dispatched in the evening. An important matter is that a single route is scheduled for delivery, followed by a single route dedicated to collection.

A strong tendency that could be observed in most urban areas during last decades was to limit the presence of the logistics platforms in urban areas. Several simple reasons can explain this phenomenon. Inhabitants do not appreciate living around these platforms that might cause increases of traffic (and specially traffic of large vehicles), generate noise and pollution, or have some unpleasant visual impact. Also, available surfaces in cities are rare and expensive. From a pure economical point of view, carriers used to prefer less expensive locations, at some distance of the city, though the inconveniences of being distant from final customers. Also, local authorities gave priority to more *noble* activities for these available surfaces: commercial centers, apartments, public services as libraries or concert halls...

Due to many recent factors, the benefits of this policy, both for local authorities and carriers (and eventually inhabitants), can be questioned. Environmental issues become more and more important. New purchase channels as e-business modify profiles of carrier customers and imply different organizations and services. Disposing of urban platforms can then offer several possibilities as using electric vehicles (whose limited autonomy prevents from travelling long distances) or scheduling several successive deliveries or collection routes (which is not tractable with distant platforms).

Though some urban platforms exist and their performance on different criteria can be analyzed, no model seems to allow quantifying *a priori* the effect of locating a platform at a given position. In this study, we propose an original model that aims at answering to the following problems:

- given a set of available surfaces in and outside of the city,
- given an average distribution activity of the city,
  - o how many logistics platforms have to be built ? where should they be located ? and how should they be sized ?
  - o how should be the vehicle fleet of each logistics platform composed of ?
  - o what should be the (approximate) daily route of each vehicle ?
- so that the distribution is performed at optimal performance regarding a set of criteria including economic, environmental and social impacts. given a set of available surfaces in and outside of the city,

Operations research literature is rich of works devoted to location of logistics platforms or design of distribution networks. Some important references are (Crainic, 2000; Daskin, 1995; Klose and Drexl, 2005; Melo *et al.*, 2009; Revelle *et al.*, 2008). While some of them concern city logistics (Crainic, 2008; Taniguchi *et al.*, 1999), none of these works address the issues investigated here.

PROBLEM DESCRIPTION AND MODELING APPROACH

Problem description

The model we propose involves a set D of spatially distributed zones of demand, a set L of available surfaces for logistics platforms and a set V of vehicles to transport goods (i) from the logistics platforms to the zones of demand, (ii) within the zones of demand through routes.

Each zone $d \in D$ has a demand of γ_d *positions* (a position being defined as a stop of a vehicle for serving a customer). All γ_d positions are distributed within d through a single route of δ_d kilometres. A set $\Delta_d \subseteq D$ of compatible zones is assigned to d ; the compatibility of zones is used to define routes of vehicles. Indeed, routes of different zones can be merged if and only if the concerned zones are compatible. A congestion cost c_d^{cong} (taking values in {A, B, C, D, E}) is assigned to d in order to represent the difficulty of driving within d; c_d^{cong} can depend on the population density of d, its topology, the width of its streets...

Each available surface $l \in L$ for logistics platforms has a size defined as a maximal number q_l of doors which can be built on l. Each door of l can ensure the distribution of θ_l positions. The distance between an available surface $l \in L$ and a zone of demand $d \in D$ is denoted M_{ld}. The total cost of selecting l is divided into four costs: (i) an economic fixed cost c_l^{selec} for the construction or the maintenance of l (euro), (ii) an economic cost c_l^{berth} for building a door on l (euro), (iii) a cost c_l^{acc} of the inhabitants acceptability ({A, B, C, D, E}) and (iv) a cost c_l^{poll} for the pollution created by a door built on l ({A, B, C, D, E}).

Each vehicle $v \in V$ has a capacity β_v (number of positions) and a distance-autonomy α_v^{dist} (Kms). The driving time per day of v is limited by two parameters: (i) α_v^{time} (minutes) which depends on the specific technical characteristics of v, and (ii) T_{max} (minutes) which is a workload limit. v is furthermore limited to travel on a subset $J_v \subseteq D$ of zones of demand (because of the legislation, the width of the streets...). Travel times in our model depend on the type of vehicles. We thus use, for each vehicle v, the notations S_{vd} and T_{vld} that respectively define the travel time for serving the zone of demand $d \in D$, and the travel time between d and an available surface for logistics platforms $l \in L$. The total cost of using v is divided into five costs: (i) an economic fixed cost c_v^{purch} for the purchase of v (euros), (ii) a driving cost c_v^{driv} (euros/Km), (iii) a cost c_v^{poll} for gas emissions of v (euros/Km), (iv) a cost c_v^{acc} of the inhabitants acceptability ({A, B, C, D, E}) and (v) a congestion cost c_v^{cong} ({A, B, C, D, E}).

Hypotheses of our model and justifications

One carrier. This paper addresses solutions for locating public logistics platforms where goods are consolidated in order to be delivered in the cities by one single carrier (public or private).

One route per vehicle. To cope with the current organization of the carriers (because of constraints on drivers, on incompressible processing times for sorting and consolidating goods in distribution centres), we assume that each vehicle cannot be assigned to more than one route per day.

One vehicle per zone of demand. To cope also with the current organization of carriers, we assume that each zone of demand is served by a single vehicle. It implies that, as in practice, the size of each zone of demand fits in at least one vehicle.

Transportation costs are estimated. Exact transportation costs are complicated to handle. Two main approaches to estimate them can be found in the literature. Either transportation costs are roughly approximated as being simply dependent on the distance between the platform and the zone of delivery; such approach does not make sense in an urban context, with a heterogeneous fleet of vehicles. Or vehicle routes are explicitly constructed (in so-called Location-Routing Problems); we do not believe that going into such deep details is necessary here, as decisions are very strategic, concern a very dynamic context (urban areas, fast delivery) and are based on very approximated/aggregated data (demand, costs...). We rather evaluate transportation costs as follows: the transportation cost of a route depends on the first zone served (indicating the cost of entering the city from a distant platform) and the set of zones of delivery (indicating the distances traveled during the deliveries). Constraints are introduced, through the use of the compatibility between zones, to avoid including distant zones in a same delivery route.

A logistic platform has a 10-year life cycle and works 300 days per year.

MIP model

In this section, we propose an Integer Linear Programming model associated with the problem at hand. For the sake of clarity, the presentation of this mathematical formulation is split into three parts: the decision variables, the constraints and the different optimization criteria of the model.

Beforehand, we define two additional sets D_v and V_d we use in our model:

$D_v = \{d \in D \mid (d \in J_v) \wedge (\beta_v \in \gamma_d)\}$
$V_d = \{v \in V \mid (d \in J_v) \wedge (\beta_v \in \gamma_d)\}$

D_v stands for the set of zones of demand the vehicle $v \in V$ can serve (it is allowed to serve the zones and its size fits their demand), and V_d defines the set of vehicles which can be used to serve the zone of demand.

Decision variables. The decision variables of our mathematical model are:

- $u_l = 1$ if a logistics platform is built on the available surface l, 0 otherwise ; $\forall l \in L$
- w_l is the number of doors to be built on the logistics platform located on l ; $\forall l \in L$
- $x_{lvd} = 1$ if the vehicle v is assigned to the logistics platform located on l and serves the zone of demand d, 0 otherwise ; $\forall l \in L, \forall v \in V, \forall d \in D_v$
- $z_{lvd} = 1$ if the vehicle v is based in the logistic platform located on l and begins its daily route by serving the zone of demand d, 0 otherwise ; $\forall l \in L, \forall v \in V, \forall d \in D_v$

Constraints.

$$w_l \leq q_l \cdot u_l \qquad \forall l \in L \tag{1}$$

$$\sum_{l \in L} \sum_{v \in V_d} x_{lvd} = 1 \qquad \forall d \in D \tag{2}$$

$$\sum_{v \in V} \sum_{d \in D_v} x_{lvd} \cdot \gamma_d \leq \theta_l \cdot w_l \qquad \forall l \in L \tag{3}$$

$$\sum_{l \in L} \sum_{d \in D_v} x_{lvd} \cdot \gamma_d \leq \beta_v \qquad \forall v \in V \tag{4}$$

$$\sum_{l \in L} \sum_{d \in D_v} (2 \cdot z_{lvd} \cdot M_{ld} + x_{lvd} \cdot \delta_d) \leq \alpha_v^{\text{dist}} \qquad \forall v \in V \tag{5}$$

$$\sum_{l \in L} \sum_{d \in D_v} (2 \cdot z_{lvd} \cdot T_{vld} + x_{lvd} \cdot S_{vd}) \leq \min(\alpha_v^{\text{time}}, T_{\max}) \qquad \forall v \in V \tag{6}$$

$$\mathcal{M} \cdot \sum_{l \in L} x_{lvd} + \sum_{l \in L} \sum_{d' \in \{\bar{\Delta}_d \cap D_v\}} x_{lvd'} \leq \mathcal{M} \qquad \forall v \in V \ \forall d \in D \tag{7}$$

$$z_{lvd} \leq x_{lvd} \qquad \forall l \in L \ \forall v \in V \ \forall d \in D_v \tag{8}$$

$$\sum_{l \in L} \sum_{d \in D_v} z_{lvd} \leq 1 \qquad \forall v \in V \tag{9}$$

$$\sum_{l \in L} \sum_{d \in D_v} x_{lvd} \leq \mathcal{M} \cdot \sum_{l \in L} \sum_{d \in D_v} z_{lvd} \qquad \forall v \in V \tag{10}$$

$$u_l \in \{0, 1\} \qquad \forall l \in L \tag{11}$$

$$w_l \in \mathcal{N} \qquad \forall l \in L \tag{12}$$

$$x_{lvd} \in \{0, 1\} \qquad \forall l \in L \ \forall v \in V \ \forall d \in D_v \tag{13}$$

$$z_{lvd} \in \{0, 1\} \qquad \forall l \in L \ \forall v \in V \ \forall d \in D_v \tag{14}$$

$$\text{with } \mathcal{M} \geq \text{card}\{D\}$$

Doors can only be built, up to the size of the site, on selected available surfaces for logistics platforms (1). The demand of each zone has to be fully fulfilled (2), i.e. a vehicle has to be assigned to each zone of demand. Constraints (3) and (4) are capacity constraints for, respectively, platforms and vehicles: we cannot assign too many positions (through the assignment of vehicles) to each platform (3) and the number of positions served by a vehicle is limited by its size (4). The daily use of each vehicle is limited by its distance autonomy (5) and its travel autonomy (6). Constraints (7) formalize constraints of compatibility between zones of demand: incompatible zones (typically zones that are distant one from each other) cannot be served in a single route. Constraints (8), (9) and (10) define the assignment of variables z_{lvd}; each first zone of a route has to be a served zone (8), each route cannot have more than one zone (9) and each route has to have a first zone (10). Constraints (11), (12), (13) and (14) define the variable domains.

Optimization criteria.

$$\sum_{l\in L}\left(c_l^{\text{selec}}\cdot u_l + c_l^{\text{berth}}\cdot w_l\right) \tag{15}$$

$$\sum_{v\in V} c_v^{\text{purch}}\cdot\left(\sum_{l\in L}\sum_{d\in D_v} z_{lvd}\right) \tag{16}$$

$$10\cdot 300\cdot\sum_{v\in V} c_v^{\text{driv}}\cdot\left(\sum_{l\in L}\sum_{d\in D_v}\left(x_{lvd}\cdot\delta_d + 2\cdot z_{lvd}\cdot M_{ld}\right)\right) \tag{17}$$

$$10\cdot 300\cdot\sum_{v\in V} c_v^{\text{poll}}\cdot\left(\sum_{l\in L}\sum_{d\in D_v}\left(x_{lvd}\cdot\delta_d + 2\cdot z_{lvd}\cdot M_{ld}\right)\right) \tag{18}$$

$$10\cdot 300\cdot\sum_{l\in L} c_l^{\text{poll}}\cdot w_l \tag{19}$$

$$10\cdot 300\cdot\sum_{l\in L}\sum_{v\in V}\sum_{d\in D_v} c_d^{\text{cong}}\cdot c_v^{\text{cong}}\cdot x_{lvd} \tag{20}$$

$$\sum_{l\in L} c_l^{\text{acc}}\cdot u_l \tag{21}$$

$$\sum_{v\in V} c_v^{\text{acc}}\cdot\left(\max_{v\in V} c_v^{purch}\cdot\sum_{l\in L}\sum_{d\in D_v} x_{lvd}\right) \tag{22}$$

As mentioned before, this paper addresses investigations about sustainable solutions for the location of logistics platforms in urban areas. The global objective function of our model is thus composed of different criteria around the three aspects of sustainability: economy (15), (16), (17), environment (18), (19), (20) and society (20), (21). Some of these objective functions manage qualitative costs ({A, B, C, D, E}). In our experiments, all these costs are converted into numerical values according to their category.

For the economic purpose, our model addresses the fixed cost of building or maintaining logistics platforms (15), the fixed cost of purchasing vehicles (16) and the variable cost of using vehicles (17).

The environmental cost function of our model is split into three parts: a variable pollution cost caused by travels of vehicles (18), a variable pollution cost caused by logistics platforms (19) and a variable congestion cost due to both vehicles and platforms.

Our model also addresses fixed acceptability costs through two criteria: the acceptability by inhabitants near logistics platforms (21) and the acceptability by inhabitants impacted by vehicles movements (22).

In a first approach, we define the global objective function of our model as the sum of these 8 optimization criteria. Future works will investigate multi-objectives methods to deal with the diversity of these criteria.

GENERIC OPTIMIZATION SOFTWARE

To experiment our model, we have developed a generic optimization tool able to create, compute and evaluate different scenarios in any urban area.

In this software, users can split a geographical urban area into different zones of demand and describe for each zone: the demand, specific vehicle traffic rules, and other properties such as size and travel time... Different types of vehicle can also be created according to their own list of attributes (which corresponds to the elements of our mathematical model). Available surfaces for logistics platforms, and their properties, can also be created and edited in our tool. Figure 1 is a screenshot of the software used on a map of Marseilles (a French city), with the editing of three data tables: available surfaces for logistics platforms, zones of demand and vehicles on Figures 2, 3 and 4, respectively.

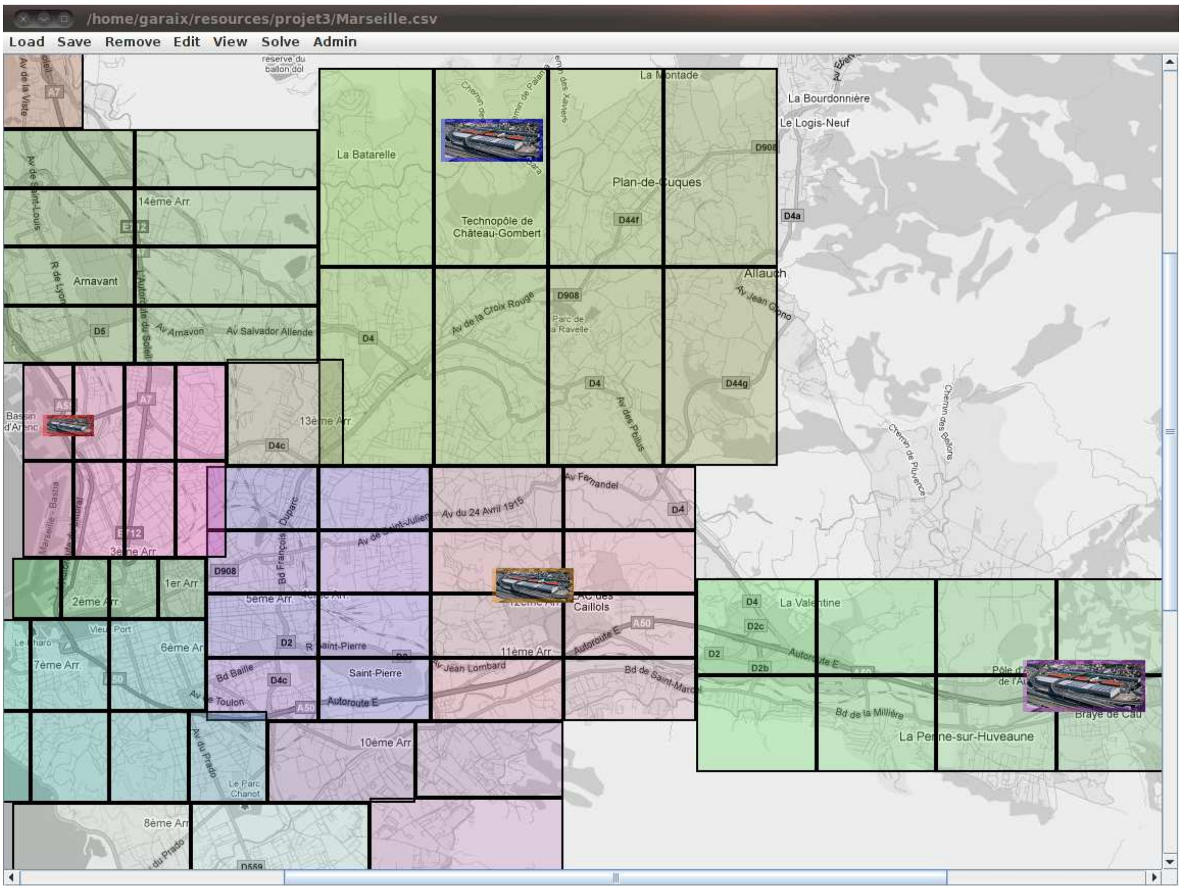
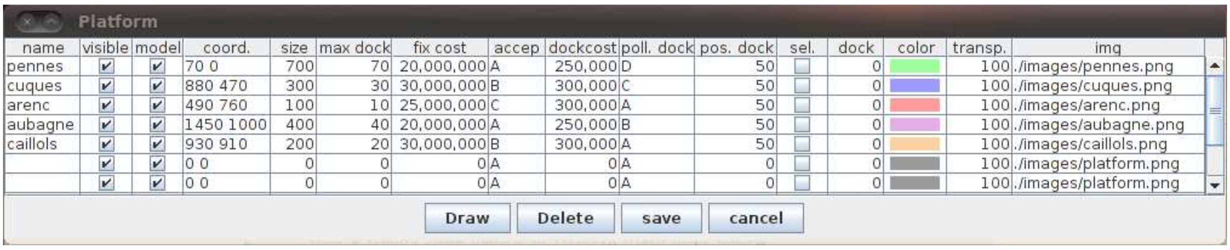


Figure 1 Optimization tool – map

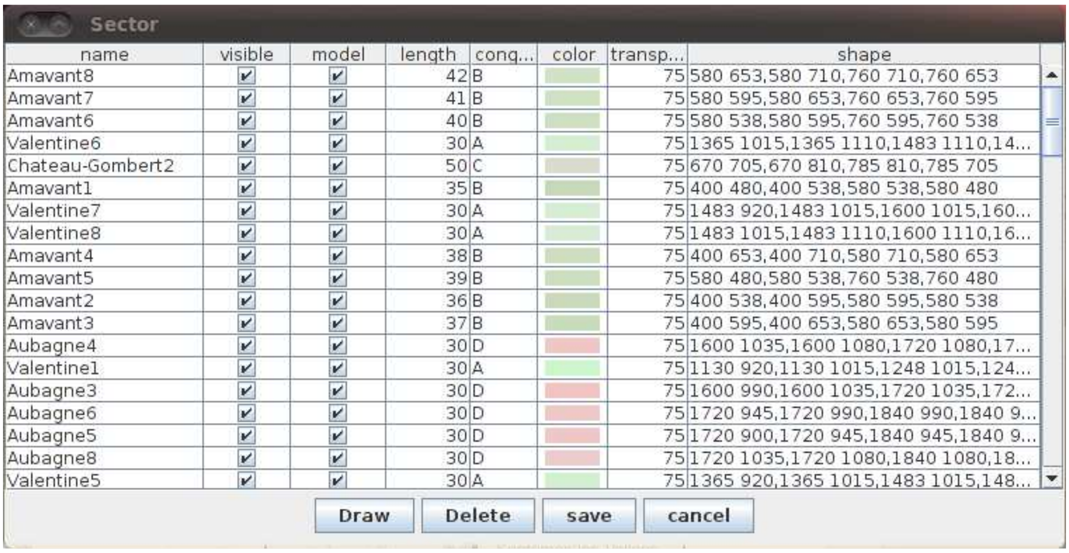


Platform

name	visible	model	coord.	size	max dock	fix cost	accep	dockcost	poll. dock	pos. dock	sel.	dock	color	transp.	img
pennes	✔	✔	70 0	700	70	20,000,000	A	250,000	D	50	☐	0		100	./images/pennes.png
cuques	✔	✔	880 470	300	30	30,000,000	B	300,000	C	50	☐	0		100	./images/cuques.png
arenc	✔	✔	490 760	100	10	25,000,000	C	300,000	A	50	☐	0		100	./images/arenc.png
aubagne	✔	✔	1450 1000	400	40	20,000,000	A	250,000	B	50	☐	0		100	./images/aubagne.png
caillols	✔	✔	930 910	200	20	30,000,000	B	300,000	A	50	☐	0		100	./images/caillols.png
	✔	✔	0 0	0	0	0	A	0	A	0	☐	0		100	./images/platform.png
	✔	✔	0 0	0	0	0	A	0	A	0	☐	0		100	./images/platform.png

Draw Delete save cancel

Figure 2 Optimization tool – platforms



Sector

name	visible	model	length	cong...	color	transp...	shape
Amavant8	✔	✔	42	B		75	580 653,580 710,760 710,760 653
Amavant7	✔	✔	41	B		75	580 595,580 653,760 653,760 595
Amavant6	✔	✔	40	B		75	580 538,580 595,760 595,760 538
Valentine6	✔	✔	30	A		75	1365 1015,1365 1110,1483 1110,14...
Chateau-Gombert2	✔	✔	50	C		75	670 705,670 810,785 810,785 705
Amavant1	✔	✔	35	B		75	400 480,400 538,580 538,580 480
Valentine7	✔	✔	30	A		75	1483 920,1483 1015,1600 1015,160...
Valentine8	✔	✔	30	A		75	1483 1015,1483 1110,1600 1110,16...
Amavant4	✔	✔	38	B		75	400 653,400 710,580 710,580 653
Amavant5	✔	✔	39	B		75	580 480,580 538,760 538,760 480
Amavant2	✔	✔	36	B		75	400 538,400 595,580 595,580 538
Amavant3	✔	✔	37	B		75	400 595,400 653,580 653,580 595
Aubagne4	✔	✔	30	D		75	1600 1035,1600 1080,1720 1080,17...
Valentine1	✔	✔	30	A		75	1130 920,1130 1015,1248 1015,124...
Aubagne3	✔	✔	30	D		75	1600 990,1600 1035,1720 1035,172...
Aubagne6	✔	✔	30	D		75	1720 945,1720 990,1840 990,1840 9...
Aubagne5	✔	✔	30	D		75	1720 900,1720 945,1840 945,1840 9...
Aubagne8	✔	✔	30	D		75	1720 1035,1720 1080,1840 1080,18...
Valentine5	✔	✔	30	A		75	1365 920,1365 1015,1483 1015,148...

Draw Delete save cancel

Figure 3 Optimization tool - zones of demand

Vehicle

name	visible	model	capa	km	min	max dur	fix cost	var cost	poll	cong	accep	qty	color	transp.	img
P_elec	✔	✔	20	100	180	480	30,000	0.035	0	A	A	30		100	./images/autoelec.p...
P_ther	✔	✔	20	600	600	480	20,000	0.18	200	A	C	30		100	./images/groscamio...
M_ther	✔	✔	40	600	600	480	30,000	0.25	350	C	D	30		100	./images/groscamio...
M_elec	✔	✔	40	100	180	480	50,000	0.035	0	B	B	30		100	./images/autoelec.p...
G_ther	✔	✔	60	600	600	480	50,000	0.4	500	E	E	30		100	./images/groscamio...
	✔	✔	0	0	0	0	0	0	0	A	A	0		100	./images/vehicle.png
	✔	✔	0	0	0	0	0	0	0	A	A	0		100	./images/vehicle.png

Delete save cancel

Figure 4 Optimization tool - vehicles

Our software has an optimization module. This module consists in optimizing the mathematical model described in the previous section using the commercial software *IBM ILOG CPLEX12.1*. The solver we propose can be tuned by the user. As the screenshot of the Figure 5 shows, the user can select available surfaces for logistics platforms and vehicle types, and define different weights to three global objectives: economy, environment and society.

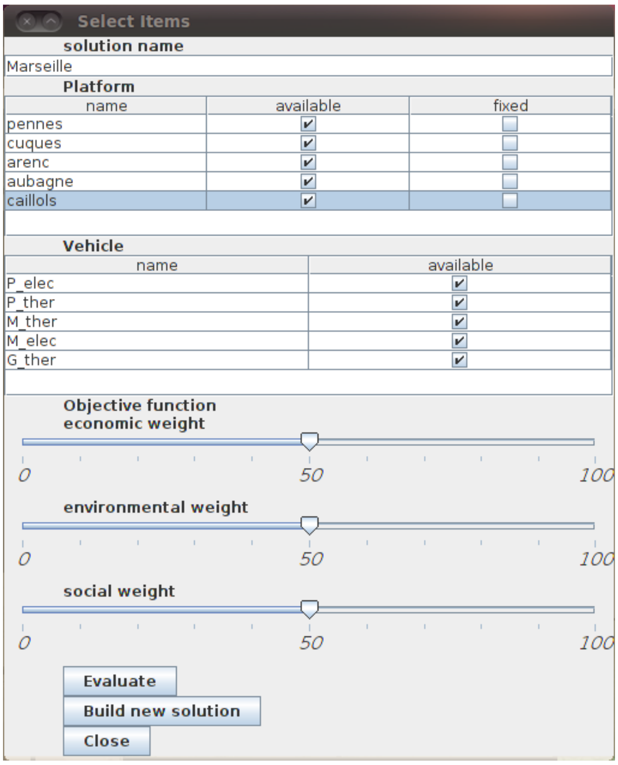


Figure 5 Optimization tool - solver

A First Case Study Based on Marseilles (France)

The study proposed in this paper is done in partnership with a French consultancy service specialized in transports economics (JONCTION) which has collected aggregate data about actual distribution systems in the second largest city of France: Marseilles (852,395 inhabitants in 2007). JONCTION indeed met thirteen companies that already operate in Marseilles and its surroundings. They thus have collected both figures and actual ways of working of these thirteen companies. The model presented above is based on the conclusions and exploits the data of this study for Marseilles.

To experiment our model and the software we have developed, we created an instance based on real data for Marseilles. In this instance, Marseilles' urban area is split into 94 sectors requiring 2957 deliveries per day. Five categories of vehicles are considered: two electric and three gasoline ones. Their maximum *carrying* capacities vary from 3.5 to 15 tons. The set of available surfaces for logistics platforms is composed of 5 localizations; three inside the urban area, and two in its surroundings.

Preliminary results for our case study consists in selecting three of the four platforms (the two ones that are inside the urban area, and one on its periphery), and using 94 vehicles. About 300 vehicles run currently each day in Marseilles for this service. Therefore, we can expect to divide by three the size of the fleet delivering Marseilles, by merging the activities of the thirteen companies.

CONCLUSION

We have proposed a new mathematical model for a strategic problem of City Logistics: the location and sizing of logistics platforms. For a concrete use of this model by local authorities of large cities, we have implemented an optimization tool for both editing data, finding a feasible solution and visualizing it. Such a tool can thus be used in order to compare different scenarios (location of candidate logistics platforms, policy rules on eligible fleet of vehicles inside the city...) and then take a strategic decision on the location of logistics platforms.

Future works will address the creation of an instance, still dedicated to Marseille, which will be based on exact data. Ad hoc solution methods will also be developed in order to find good feasible solutions in a reduced CPU time. For the moment, we use a commercial optimization software that meets difficulties for solving very large instances.

In our presentation for the 7th International Conference on City Logistics, we will present our model and precisely describe the data we use for our case study (Marseille). We will also present an ad hoc solution method and its associated concrete results. An application of the optimization software we have implemented will also be demonstrated.

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